

STUDIES AND APPLICATIONS ON ADVANCED PURIFICATION OF DRINKING WATER

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ABSTRACT

The four advanced purification process combinations were proposed in sight of the analysis of the source water qualities by GC/MS. The results of the parallel experiments show that ozonation/biological activated carbon process can improve the aesthetic characteristics of water such as turbidity, color. Moreover, the process can remove the harmful trace organic pollutants offer high quality potable water in compliance with EEC water quality standards. The process was applied successfully in the Northeast of China in full-scale. The treated water quality was in compliance with the stipulated standards. The same process was also put into practice in Shenzhen for bottled and piped high-quality water full-scale application. And the water quality of the municipal water supply can be improved to the first-rate in the world, by means of application of the process in the municipal water plant in a near future.

KEYWORDS

Advanced purification, Ozonation, Biological activated carbon, Air blasting, Slow sand filtration.

1. INTRODUCTION

The degradation of raw source water has become a worldwide problem, and more serious in developing countries. Safe and healthy drinking water is paid more and more attention. The rapid economic development and increasing polluted sources water put forward the need for advanced purification of drinking water in order to remove the trace pollutants in the water after conventional treatment. For instance, the source water of a city in the Northeast of China was found polluted. Vertigines and trichomadesis appeared among the inhabitants. The cancer cases were reported in an increasing number. Routine monitoring detected excess chloroform and tetrachloromethane in the drinking water. And COD_{Mn} ,

the gross organic pollution index, was 3.6-6.8 mg/l exceeding EEC Water Quality Standard for drinking water ¹. Analysis by GC/MS revealed 166 organic pollutants such as alkanes, alkenes, alkynes aldehydes, phenols, amine, aromatic hydrocarbon, 7 in which were prior pollutants including methylbenzene, ethylbenzene, brom-dichloro-methane etc., listed by the US EPA ². These trace organic pollutants might be harmful to human health, and lead to increasing cases of cancers or chronic diseases on liver, kidney, spleen and other organs after drinking over a long period of time ³. The results showed that the local drinking water had been contaminated seriously. And the pollution cannot be eliminated by conventional treatment. Therefore, an advanced purification is necessary for drinking water.

2. EXPERIMENTS AND RESULTS

Along with the pollution of source water, more and more importance has been attach to the technologies on advanced purification of drinking water, of which ozonation and biological activated carbon (ozonation/BAC) process has got yearly investigation and found wide use in the world ^{4&5}. The advantages of ozonation/BAC process lie in : 1. After contact of ozone with water, a part of organic pollutants are decomposed into H₂O and CO₂, and removed from water, resulting in reduced organic loading on the succeeding BAC beds; 2. The main part of organic pollutants are degraded intermediate products with low molecular-weight, which are biodegradable and/or liable to be adsorbed by BAC or the biofilm on it; 3. Oxygen and residual ozone in the water after ozonation, offer activated carbon bed column with sufficient oxygen suitable for growth of aerobic microbes on activated carbon granules. Therefore, the capacity for organic pollutant removal increases significantly with a prolonged service life of activated carbon.

2.1 Experiment processes

At the flow rate of 1m³/hr, the raw water for the pilot plant has been pretreated by conventional process, shown as follows:

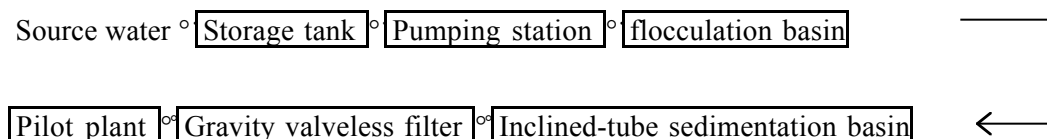
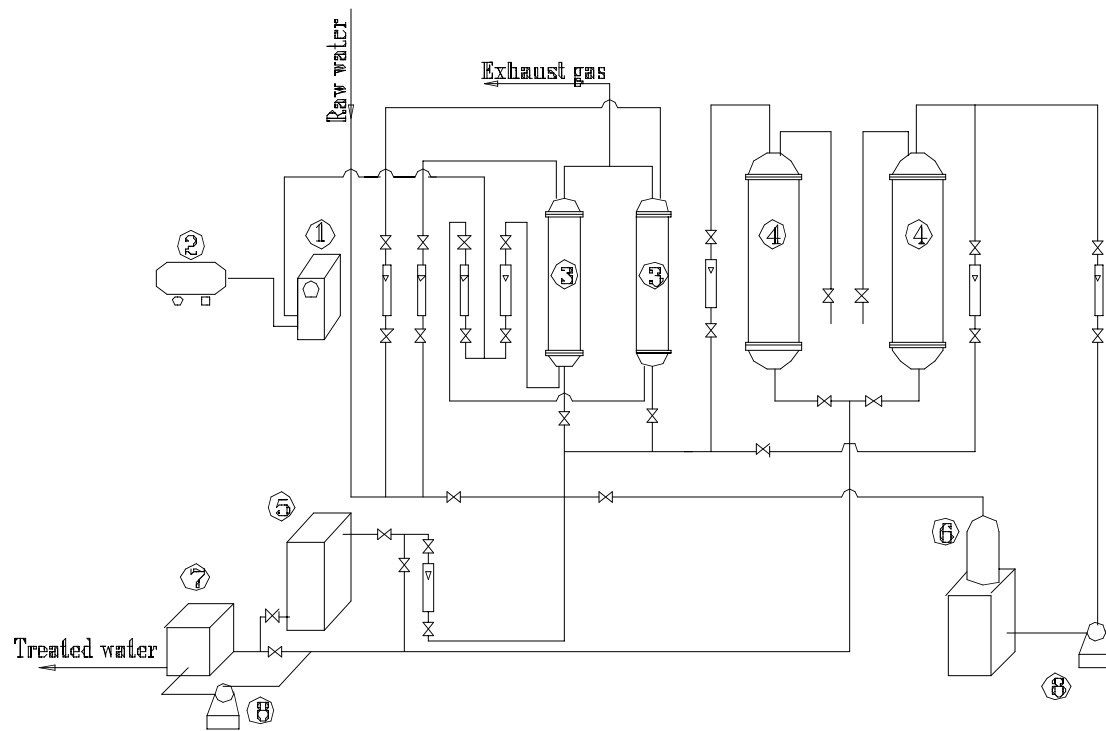


Figure 1 Pretreatment process flow chart

The raw water, or the filtered water in the conventional treatment plant, was treated with the processes such as ozonation, BAC filtration (adsorption/biodegradation), slow sand filtration, air blasting. The flow sheets are shown as follows:

- A. Raw water° Ozone contact° BAC filtration° Treated water
- B. Raw water° Ozone contact° Slow sand filtration° Treated water
- C. Raw water° Air blasting° BAC filtration° Treated water
- D. Raw water° Ozone contact° BAC filtration° Slow sand filtration° Treated water

The layout of the pilot plant is shown in Figure 2.



Legend: ①-Ozone generator; ②-Air compressor; ③-Ozone contactor; ④-BAC bed;
⑤-Slow sand filter; ⑥-Air blasting unit; ⑦-Storage tank; ⑧-Pump.

Figure 2 The layout of the pilot plant for advanced purification

The pretreatment of raw water is favorable to remove the organic pollutants and reduce the formation potential of THMs, and give a full play of treatment capacity in ozonation/BAC process ⁶.

The pilot plant is integrated with the four main parts, including ozonation unit, GAC filters, air blasting unit and slow sand filter.

- A. Ozonation unit includes 1 set of XY-3 Type ozone generator with operation pressure at 0.04-0.08 MPa, adjustable voltage of 8-15kV, ozone production capacity of 1-15g/hr. And 2 ozone contactors, were installed with the height of 1.65m and the diameter of 400mm. The water velocity in the contactor is 4-6m/hr with ozonation contact time of 10-20min. Ozone dosage can be adjusted between 1-15 mg/l.
- B. 2 GAC filters, with diameter of 400mm and bed depth of 2.4m, can be run in parallel or series pattern. The filter velocity can be controlled at 2-5m/hr with GAC bed contact time of 18-30 min.
- C. Air blasting unit consists of a aeration column with the diameter of 400mm and the packing media height of 0.9m, and a collection tank with the area of 1m² and the height of 1.5m. The unit is run at flow rate of 1.0m³/hr with air to water ratio of 2.4 and aeration time of 15 min.
- D. Slow sand filter is installed with the sand of grain size 0.2-0.4mm and filtering area of 1.0m² and 1.0m. The filter velocity is 0.15m/hr.

2.2 Routine analysis of water quality

Routine analyses were conducted of the source water, filtered water and treated water from each process. The results showed that most of suspended solids and color-forming substances were removed after conventional treatment. The turbidity was reduced to 3-5 NTU, color to 4-13 unit. The other items were also in compliance with the National Water Quality Standards on the whole. Compared with EEC water quality standards, however, COD_{Mn}, the comprehensive index for organic pollutants in the filtered water, was 3.6-6.8 mg/l, exceeding the EEC standards (2.0mg/l). Therefore, the investigation was focused on the removal of organic pollutants in each process. COD_{Mn} in the water was found below 2.0 mg/l after treatment by ozonation/BAC (process A), ozonation/BAC/slow sand filter (process D). Meantime, nearly unchanged hardness and trace element concentrations demonstrated that the water quality was improved without undesirable changes after the advanced purification.

According to the results in Table 1, process A and Process D in the four process

combinations could produce desirable treated waters. Process D is not economical in area requirement and capital investment, compared with process A. Therefore, the investigation was stressed on process A.

TABLE 1
PROCESS PARAMETERS AND PERFORMANCE

Process Parameter	Ozone/BAC	Ozone/sand	Air/GAC	Ozone/BAC/sand
Flow rate (m/hr)	0.3	0.3	0.3	0.3
Ozone dosage (mg/l)	2-4	2-4		2-4
Bed depth (m)	1.05	1.1	1.05	1.05,1.1
Flow velocity (m/hr)	2.38	0.30	2.38	2.38,0.30
Contact time (min.)	26	220	26	26,220
COD _{Mn} (mg/l)	0.8-2.0	3.0-3.3	2.3-3.3	0.8-1.8
%COD _{Mn} (%)	73.1	39.4	45.2	75.0
Turbidity (NTU)	0	0	0	0
pH	8.0-8.1	7.9-8.1	8.0-8.2	8.0-8.1

Note: 1. COD_{Mn} in the raw water was 4_6.8mg/l.

2.The flow rate was controlled at 0.3m³/hr.

Turbidity is a measure of the ability of water to scatter light. It can be caused by any small particles, which are suspended in the water, for example clay, algae and colloidal organic material. After conventional treatment, the turbidity in the water decreased to 3-5 NTU, which met the National Standards for drinking water concerning aesthetic acceptability. When the water was boiled, however, a kind of yellowish flocs appeared in the water. Their evaporation residue was found at loss of 45 % in weight after calcine. This reveals that nearly half of the flocs were organic pollutants. The turbid boiled water resulted from destabilization of the colloidal organic pollutants when heated. The turbidity in the treated water from ozonation/BAC was tested and shown in Figure 3. The turbidity decreased from 3-5 NTU in

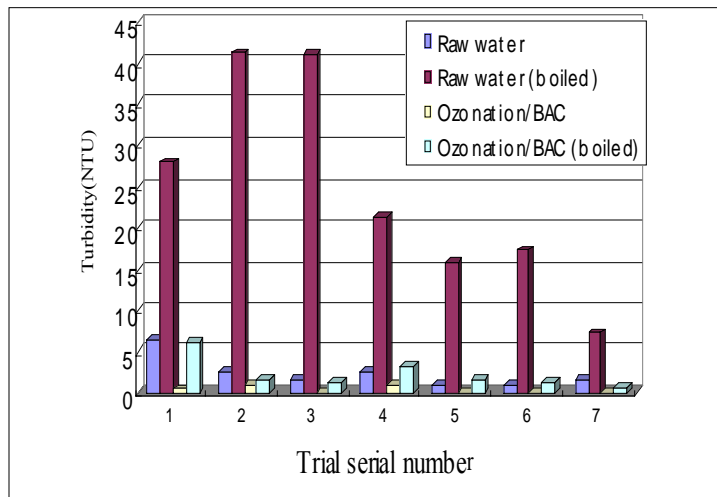


Figure 3 Turbidity removal by conventional treatment vs. advanced purification

the raw water, to 0 NTU in the treated water, from 40 NTU in the raw water to 1-2 NTU in the treated water when boiled. This also reveals a much better water quality after ozonation/BAC treatment.

2.3 Analysis by GC/MS/DS

The water samples from the raw water, the raw water chlorinated, the treated water (by ozonation/BAC) and the treated water chlorinated were analyzed by GC/MS/DS after concentration and enrichment procedures. The total ion current chromatographs for the water samples are shown in Figure 4-7 respectively.

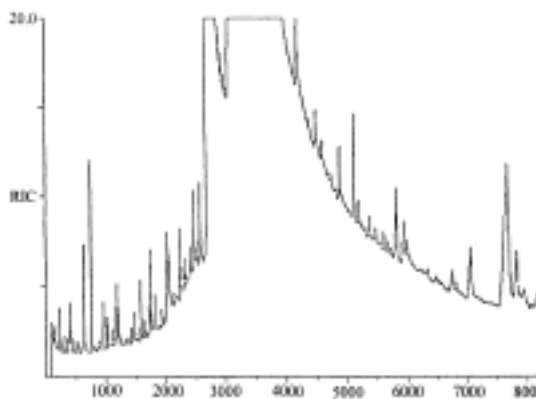


Figure 4 Total ion current chromatograph
for the raw water

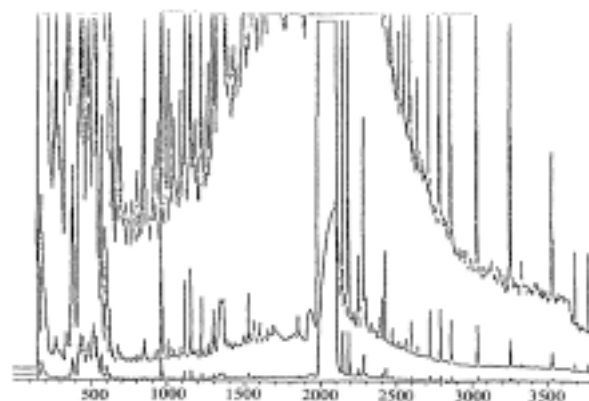


Figure 5 Total ion current chromatograph
for the raw water chlorinated

Figure 6 Total ion current chromatograph
chromatograph
for the treated water

Figure 7 Total ion current
for the treated water chlorinated

It is shown that the organic compositions were very complicated in both the raw water and the raw water chlorinated. In the raw water, 127 species of organic compounds were identified. Among them, 5 were prior pollutants stipulated by the U.S. EPA, and nearly 30 were potential toxic substances. After ozonation/BAC treatment, most of the organic compounds were removed. Those remained were in a significantly lower concentration and almost harmless to human health. The effectiveness of ozonation/BAC process for organic pollutant removal lies in that after ozonation in ozone contactor, the organic components in the water were decomposed into intermediates of lower molecular-weight such as aldehydes, ketones, alkenes and acids, which were liable to adsorbed and biodegraded by the subsequent BAC bed. As a result, the organic pollutants were removed, and an excellent water quality was obtained in treated water.

According to the results, in the treated water chlorinated, only 6 species of organic compounds were identified. Compared with the treated water (see Figure 6 and Figure 7), the species and their amount remained roughly unchanged, and no THMs formed. This manifested that ozonation/BAC process can produce a high-grade drinking water. The organic compounds were so few in their species and so low in their concentration that the precursors of THMs were eliminated and THMs formation was controlled.

3. APPLICATIONS

3.1 The full-scale application in the Northeast of China

Located in Daqing City, the important petroleum producing area and petrochemical base, Daqing Petrochemical Complex is one of leading enterprises in Chinese petrochemical

industry. Its source water is transported through an open canal from Nenjiang River. The source water is polluted because of the industrial and agricultural development near the canal these years, leading to cancer cases increased among the local inhabitants. After water quality analysis and experiment on site, the research achievement was applied successfully in the new-built advanced water purification plant (see figure 8) in the Complex. At the capacity of 20,000 m³/day, the plant purifies the water with the process as follows:

Filtered water → **Ozone contact** → **BAC filtration** → **Post sand filtration** → **Chlorination** → Treated water

The airproof ozone contactors are used with a special ball-cage contact carriers installed. The ozone contact time is shortened to 5-6 minutes from 10-15 minutes because of the mass transfer improved. The ozone exhaust is treated with HOZ Catalytic/thermal Ozone Destroyer (see figure 9), designed by ourself. The equipment can destroy ozone exhaust without dehumidification. It controls heater and blower automatically, and works stably and reliably.



Figure 8 The advanced water purification plant in Daqing Petrochemical Complex Figure 9 HOZ Catalytic/thermal Ozone Destroyer

The performance of the advanced water purification plant in Daqing Petrochemical Complex achieves the standards proposed in the experiment. It can be concluded that ozonation/BAC process tackles the local water pollution problem effectively.

3.2 The practice of advanced water purification in Shenzhen

The main water source for Shenzhen is Shenzhen Reservoir. The water is polluted by the industrial and domestic wastewater, as well as pesticides and fertilizers flushed from the farm during its transportation. From the East River on the coast, the seawater intrusion pollution

makes an adverse impact on the drinking water treatment in water supply enterprises in Shenzhen.

In the progress to build an modern international metropolitan, it is extremely important to improve the water quality up to the first-rate standard in the world. Therefore, Shenzhen Water Supply Group (SWSG) takes the lead in producing bottled high-quality drinking water, at the capacity of 150 m³/day, with an advanced water purification technology (see figure 10,11). The product line takes the tap water as its raw water, and its process is shown as follows:

Tap water°Ozone contact°Two-stageBAC filtration°Ultra-filtration°Ozonation°Treated water

The product water quality is in good accordance with EEC water directives after examination. It has enjoyed growing favour among the inhabitants for its high clearness and good taste.

On base of the experience in bottled high-quality water production, SWSG has conducted a piped high-quality water project in Meilin residential quarter. As for the municipal water supply in Shenzhen, it is a feasible approach at present to improve water quality partially by dual pipe system. At the capacity of 200 m³/day, the piped high-quality water system can meet the demand for 7,000 households in the residential quarter. The system will be put into operation in this May.



Figure10 The bottled high-quality
water plant



Figure11 The bottled high-quality water
production line

SWSG has worked out a plan to renovate its Meilin water plant, at the capacity of

600,000 m³/day, with ozonation/BAC process. The shop drawing for the project will be completed this year, and the rebuilt water plant will be put into operation in two years. At that time, the water quality will be improved entirely among the whole municipal water supply system in Shenzhen. It will be a vital stride toward the drinking water quality to join the international track.

4. CONCLUSION

4.1 Accordance with the local source water and the raw water, ozonation/BAC, ozonation/BAC/slow sand filtration could improved the water quality significantly. In the treat water, the turbidities approached 0 NTU, COD_{Mn} less than 2.0 mg/l.

4.2 The further investigation on ozonation/BAC process revealed that the process could eliminate the harmful organic pollutants and THMs precursors. It could produce a safe and high-grade drinking water.

4.3 The ozonation/BAC process was applied in the Northeast of China successfully. The treated water quality was in compliance with the stipulated standards. And the problem caused by the local water pollution was tackled effectively.

4.4 The same process was also put into practice in Shenzhen for bottled and piped high-quality water full-scale application. The municipal water quality can be improved to the first-rate in the world, by application of the process in the municipal water plant in a near future.

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